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Tillage Intensity and Fertility Level Effects on Nitrogen and Carbon Cycling in a Vertisol

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ABSTRACT

Because of erosion problems, an effort has been undertaken to evaluate the effect of tillage intensity on carbon (C) and nitrogen (N) cycling on a vertisol. Soil samples at 0-10, 10-20, and 20-30 cm depth were collected from a split plot experiment with five different levels of tillage intensity on Houston Black soil (fine, montmorillonitic, thermic Udic Pellusterts). The experiment was a split plot design with 5 replications. The main plots were chisel tillage, reduced tillage, row tillage, strip tillage, and no tillage. The subplots were soil fertility levels with either high or low fertilizer application rate. Total N, total phosphorus (P), organic C, inorganic N, and C:N ratio were measured on soil samples as well as the potential C mineralization, N mineralization, C turnover, and C:N mineralization ratio during a 30 d incubation. Total P and organic C in soil were increased, with 0.9 and 0.8 kg P ha^{-1} and 20.6 and 20.0 kg C ha^{-1}, for high and low soil fertility, respectively. Fertilizer application had no effect on either total N at the 0-10 cm depth, or on soil nutrient status below 10 cm. Potential soil N mineralization was decreased at the 0-10 cm depth and increased at the 20-30 cm depth by the high fertilizer treatment. Chisel tillage decreased total N and P in the 0-10 cm depth, with 1.4 and 1.6 kg N

ha^{-1} and 0.8 and 0.9 kg P ha^{-1}. However, chisel tillage increased total N and P at the 10-20 cm depth, with 1.3 and 1.2 kg N ha^{-1}, and 0.72 and 0.66 kg P ha^{-1} for chisel tillage and no tillage, respectively. Tillage intensity increased C mineralization and C turnover, but reduced N mineralization at the 0-10 cm depth. The results indicate that intensively tilled soil had a greater capacity for C mineralization and for reductions in soil organic C levels compared to less intensively tilled systems.

INTRODUCTION

Soils with high shrink/swell potential are difficult to manage because of their physical characteristics, including high water-holding capacity, high plasticity, high erodibility, great strength when dry, and a limited range of soil water content when soil tillage can be performed (Potter and Chichester, 1993). These characteristics lead to difficulties when implementing conservation tillage practices for erosion control and environmental protection. A management system using raised wide beds has been proposed as a conservation tillage system for these soils (Morrison et al., 1990), utilizing furrows between beds as surface drainways and as controlled-traffic lanes to support tractors during wet periods. While this system has been found to work fairly consistently both with and with out soil tillage (Morrison et al., 1994), there is a need to determine the effect of tillage intensity on soil nutrient characteristics within these wide bed systems.

The viability of any crop production system depends on maintaining adequate soil plant nutrients and organic C levels, which can be altered by tillage systems. Conservation tillage systems increase soil N concentrations as a result of immobilization (Gilliam and Hoyt, 1987), and increase N losses from both leaching (Tyler and Thomas, 1977) and denitrification (Gilliam and Hoyt, 1987). Soil moisture and temperature, which are affected by tillage systems, change C and N dynamics (Wood et al., 1991; Tracy et al., 1990). The objective of this study was to determine the impact of tillage intensity and fertilizer application rate on the C and N dynamics in a vertisol.

MATERIALS AND METHODS

A tillage study was initiated in 1990 at the Grassland, Soil and Water Research Laboratory at Temple, TX (31°05'N, 97°20'W) on a Houston Black clay soil (fine, montmorillonitic, thermic Udic Pellusterts) with five levels of tillage intensity. The tillage intensity study was imposed on an existing tillage study consisting of no tillage and conventional tillage systems. The no tillage system had been maintained continuously for more than 10 years. These five tillage systems imposed in this study consisted of: 1) chisel tillage (Chisel); 2) reduced tillage (reduced); 3) row tillage (row); 4) strip tillage (strip); and 5) no tillage (no-till). The chisel tillage system consisted of flail-shredding residue, tandem disking,

TABLE 1. Summary of annual tillage treatment operations.[a]

Operation	Chisel	Reduced	Row	Strip	No-Till
Flail chop residue	X	X			
Chisel plow	X				
Tandem disk	X	X			
Field cultivate	X				
Rebed	X	X			
Slot plant	X	X	X	X	X
Cultivate (spring)			X		

[a]Chisel = conventional chisel tillage system, reduced = reduced tillage system, row = no tillage except one sweep cultivation, strip = no tillage except row raking at planting, no-till = no tillage.

chisel tilling, tandem disking, field cultivating, and rebedding. The reduced tillage system consisted of flail-shredding residue, tandem disking, and rebedding. The row tillage system consisted of no pre-plant tillage, but cultivating once during the growing season with sweep cultivators. The strip tillage system consisted of no pre-plant tillage, but utilizing a rolling trash rake before planting. The no tillage system consisted of no pre-plant tillage and planting with a slot planter. The chisel tillage system was considered to be a conventional tillage system, while the other tillage systems are some form of conservation tillage systems. A summary of these field operations for the five tillage systems are given on Table 1.

The experimental design was a split-plot with a randomized complete block with five replications. The main-plots were five tillage levels and the subplots were soil fertility level.

The management system in these plots were composed of raised beds (61.0 m long, 1.5 m wide, and 0.15 m high), separated by 0.5 m furrows that act as traffic lanes and surface drainways (Morrison et al., 1990). The experiment included also a three crop rotation system, consisting of cotton (*Gossypium hirsutum* L.) followed by corn (*Zea mays* L.) followed by grain sorghum [*Sorghum bicolor* (L.) Moench]. The main plots were split into high and low soil fertility levels each of 30.5 m in length. The high fertility level consisted of application of 56 kg N ha^{-1} and 17 kg P ha^{-1} to cotton, 168 kg N ha^{-1} and 37 kg P ha^{-1} to corn, and 140 kg N ha^{-1} and 32 kg P ha^{-1} to grain sorghum. The low soil fertility level consisted of application of 28 kg N ha^{-1} and 12 kg P ha^{-1} to all three crops.

Soil samples were collected on April 28, 1993, at 0-10, 10-20, and 20-30 cm depth after the grain sorghum crop during the previous growing season, and stored at 5°C until processing for laboratory and incubation procedures. Subsamples of the soils were dried at 60°C, ground to pass a 0.15-mm sieve, and analyzed for total N and total P content colorimetrically on a Technicon Autoanalyzer, following digestion by a salicylic acid modification of a semimicro-Kjeldahl procedure (Technicon Industrial Systems, 1976). Soil organic C was determined with a LECO CR12 Carbon Determinator (LECO Corp., Augusta, GA) (Chichester and Chaison, 1992).

Methods used by Wood et al. (1994) were utilized for determinations of potential C and N mineralization of soil samples. Soil inorganic N (NO_2-N + NO_3-N and NH_4-N) was extracted with 2M KCl and measured (before and after incubation) by standard colorimetric procedures using a Technicon Autoanalyzer (Technicon Industrial Systems, 1973a, 1973b). Sieved soil samples (>2 mm fractions) were weighed (25 g dry weight basis) and placed in plastic containers. Deionized water was added to adjust soil water content to a redundant value equivalent to -20 kPa at a bulk density of 1.3 Mg m^{-3}. Containers were placed in sealed glass jars containing 20 mL of water for humidity control and a CO2 trap 20 mL composed of a vial of 1M NaOH. Jars were incubated in the dark at 25°C and removed after 30 days. Carbon dioxide in the NaOH traps was determined by titrating excess base with 1M HCl in the presence of $BaCl_2$. Potential C mineralization was the difference between CO_2-C captured in sample traps and in blanks. Potential N mineralization was the difference between final and initial inorganic N contents for the incubation. The C mineralization divided by total organic C was used to calculate C turnover.

Statistical analyses were performed using GLM procedure of SAS (SAS Institute, 1982), and means were separated using least significant difference (LSD) at an *a priori* 0.10 probability level.

TABLE 2. Effect of tillage system and soil fertility treatment on grain sorghum yield in 1992.[a]

Fertility[b]	Chisel[c]	Reduced[c]	Row[c]	Strip[c]	No-Till[c]
	(kg ha^{-1})				
Low	3442	3185	1630	3726	3701
High	6441	5200	3087	6127	5766

$LSD_{0.10\ fertility\ treatment}$ = 348
$LSD_{0.10\ tillage\ treatment}$ = 550

[a]Values represent means of 5 replicates.
[b]High = high fertilizer application rate, low = low fertilizer application rate.
[c]Chisel = conventional chisel tillage system, reduced = reduced tillage system, row = no tillage except one sweep cultivation, strip = no tillage except row raking at planting, no-till = no tillage.

RESULTS AND DISCUSSION

Residue Inputs

The high fertility treatment resulted in increased grain yield of grain sorghum, the crop immediately preceding soil sampling, compared to the low soil fertility treatment (Table 2). The row tillage system resulted in a lower grain sorghum yield compared to the other tillage systems in both the high and low soil fertility treatments (Table 2). It is believed that this lower yield may have resulted from root pruning of plants during cultivation. Above ground dry matter levels measured on June 3, 1992 were 56% lower for the strip tillage treatment compared to the average of the other tillage treatments (data not shown). Though residue inputs were reduced in the strip tillage treatment, the percent ground cover measured at planting was not detrimentally affected compared to the other conservation tillage treatments (Potter et al., 1996). Similar differences between treatments were noticed in these plots in previous years with the other crops in the rotation. A more detailed discussion of the corn and grain sorghum growth and productivity within these tillage system was reported previously by Potter et al. (1996).

Soil Chemical Analysis

At the 0-10 cm depth, the high fertility treatment increased soil total P, organic C, and inorganic N content compared to the low soil fertilizer application treatment (Table 3). The inorganic N content of the soil was increased with the high fertility treatment, though no significant differences were observed in either the total N content or the C:N ratio of soil due to the fertility treatment. The increased C level in the soil reflected increased C inputs from plant residue as soil fertility increased (Table 2). This increased soil C, however, was not sufficient to alter the C:N ratio of the soil (Table 3).

No effect for soil fertility treatments were observed at either the 10-20 or the 20-30 cm soil depth, indicating that changes to the soil environment due to fertilizer inputs, including increased biomass inputs, were restricted to the top 10 cm of soil. No significant interaction was observed for fertility level and tillage intensity for the nutrient measurements at any soil depth. Changes in soil nutrient status due to soil fertility treatment were small compared to both the level of increased fertilizer inputs and the difference in biomass inputs with the high fertility treatment (Table 3). These differences were also small compared to the differences observed between tillage treatments (Tables 3 and 4). The small differences due to fertilizer application were supported by results of other research on long term effects of fertilizer application and conservation tillage systems (Franzluebbers et al., 1994; Dalal, 1989).

Tillage intensity had a significant affect on soil total P, total N, organic C content, and soil C:N ratio at the 0-10 cm depth, and the total N and P content at the 10-20 cm depth (Table 4). Total P was significantly lower for the row tillage treatment

TABLE 3. Effect of soil fertility treatment on soil inorganic N, total P, total N, organic C content, and C:N ratio at 0-10, 10-20, and 20-30 cm depth.[a]

Fertility[b]	Inorganic N	Total P	Total N	Organic C	C:N
	(mg kg^{-1})		(g kg^{-1})		(g g^{-1})
0-10 cm					
High	14.0 a	0.86 a	1.59 a	20.6 a	13.1 a
Low	10.4 b	0.80 b	1.55 a	20.0 b	12.9 a
10-20 cm					
High	7.5 a	0.67 a	1.22 a	15.5 a	12.7 a
Low	7.2 a	0.65 a	1.23 a	15.4 a	12.6 a
20-30 cm					
High	6.6 a	0.53 a	1.07 a	13.5 a	12.6 a
Low	7.7 a	0.53 a	1.10 a	13.9 a	12.6 a

[a]Values represent means of 5 replicates. Means within a column followed by the same letter do not differ significantly (0.1 level).

[b]High = high fertilizer application rate, low = low fertilizer application rate.

in the 0-10 cm depth compared to the other tillage treatments. These differences in total P with row tillage closely resembled the result observed for grain sorghum yield (Tables 2 and 4), with the P concentration for row cultivation being much lower compared to the other tillage systems. This was believed to be caused by the deposition of P with the crop residue on the soil surface increasing P concentration in soil with the other treatments. Lower yields observed with the row tillage system resulted in lower P deposition, thus lower total P content in the surface soil compared to the other tillage systems. A similar effect was observed at the 10-20 cm depth. These differences in total P were not observed below the 10-20 cm depth.

At the 0-10 cm depth, total N and P were lower in the chisel tillage treatment compared to the other tillage treatments (Table 4). However, at the 10-20 cm depth, total N and P content were higher in the chisel tillage treatment compared to the other tillage treatments. This was attributed to the physical mixing of the soil with chisel plowing in the chisel tillage treatment, where the deposition of plant nutrients and fertilizer applications of N and P were mixed to deeper depths. At the 20-30 cm depth, no significant tillage effect was observed for total N and total P. This would be consistent with the changes in nutrient stratification between conventional and conservation tillage systems, since the 20-30 cm depth would be below the plow layer and would therefore not be directly impacted by the physical mixing of soil. Stratification of total P and N content in the soil profile with conservation tillage systems was in support of previous work on vertisols indicating that the impact of tillage systems was mostly observed in the top 5 cm of soil (Tracy et al., 1990; Baldesdent et al., 1990; Dalal, 1989; Potter and Chichester, 1993; Morrison and Chichester, 1994). Increased losses of soil nutrients due to erosion with the conventional tillage system compared to the conservation tillage systems could have also contributed to lower total N and P content in the 0-10 cm depth for the chisel tillage treatment compared to the other reduced tillage treatments.

At the 0-10 cm depth, the soil organic C content for the chisel tillage system was the same or lower than the conservation tillage systems, with a significantly lower value compared to the reduced tillage system (Table 4). However, unlike total N and P, the organic C content was not increased at the 10-20 cm depth in

TABLE 4. Effect of tillage system on soil inorganic N, total P, total N, organic C content, and C:N ratio at 0-10, 10-20, and 20-30 cm depth.[a]

Tillage[b]	Inorganic N	Total P	Total N	Organic C	C:N
	($mg\ kg^{-1}$)		($g\ kg^{-1}$)		($g\ g^{-1}$)
0-10 cm					
Chisel	8.4 a	0.78 c	1.41 a	19.8 a	14.0 a
Reduced	15.8 c	0.93 a	1.62 b	21.4 b	13.3 ab
Row	14.0 bc	0.67 d	1.63 b	21.0 ab	13.1 ab
Strip	11.3 ab	0.85 bc	1.61 b	19.7 a	12.2 b
No-Till	11.4 ab	0.91 ab	1.57 b	19.7 a	12.6 b
10-20 cm					
Chisel	7.0 a	0.72 a	1.30 a	16.2 a	12.5 a
Reduced	8.4 a	0.68 ab	1.25 ab	15.1 a	12.1 a
Row	8.3 a	0.60 c	1.20 b	16.0 a	13.3 a
Strip	6.4 a	0.63 bc	1.19 b	14.8 a	12.4 a
No-Till	6.6 a	0.66 abc	1.20 b	15.3 a	12.8 a
20-30 cm					
Chisel	7.3 a	0.53 a	1.08 a	12.5 a	11.6 a
Reduced	8.5 a	0.53 a	1.08 a	13.2 a	12.3 a
Row	7.8 a	0.51 a	1.08 a	13.5 a	12.5 a
Strip	6.0 a	0.52 a	1.07 a	14.8 a	13.9 a
No-Till	6.0 a	0.55 a	1.12 a	14.3 a	12.8 a

[a]Values represent means of 5 replicates. Means within a column followed by the same letter do not differ significantly (0.1 level) as determined by LSD.

[b]Chisel = conventional chisel tillage system, reduced = reduced tillage system, row = no tillage except one sweep cultivation, strip = no tillage except row raking at planting, no-till = no tillage.

chisel tillage compared to the other tillage systems. The concentration of organic C and N was also lower with chisel tillage, though soil C:N ratio was higher compared to the conservation tillage systems, with a decreased C:N ratio as the level of tillage intensity decreased (Table 4). This indicated that mechanisms other than physical plowing affected the distribution of organic C in the soil profile.

Soil Incubation

Soil incubation from soil samples at the 0-10 cm depth indicated that increasing tillage intensity tended to reduce C mineralization and C turnover (C mineralization/

TABLE 5. Effect of tillage system on C mineralization, C turnover, N mineralization, and C:N mineralization ratio at 0-10, 10-20, and 20-30 cm depth.[a]

Tillage[b]	C Mineralization	C Turnover	N Mineralization	C:N Mineralization
	(mg kg^{-1})			
0-10 cm				
Chisel	385 a	1.96 a	5.61 ab	107 a
Reduced	339 ab	1.60 ab	2.99 a	103 a
Row	332 ab	1.59 ab	6.80 ab	12 b
Strip	298 b	1.49 b	9.59 b	82 ab
No-Till	326 ab	1.66 ab	20.41 c	17 b
10-20 cm				
Chisel	176 a	1.09 a	17.15 a	12 a
Reduced	222 a	1.44 a	16.20 a	149 a
Row	170 a	1.08 a	8.59 a	3 a
Strip	177 a	1.21 a	14.40 a	14 a
No-Till	233 a	1.52 a	10.01 a	37 a
20-30 cm				
Chisel	113 a	0.91 a	11.37 bc	8 a
Reduced	216 a	1.56 a	17.15 ab	20 a
Row	134 a	1.00 a	23.31 a	96 a
Strip	132 a	0.90 a	8.28 c	17 a
No-Till	169 a	1.16 a	7.01 c	34 a

[a]Soil incubated at 25°C for 30 days. Values represent means of 5 replicates. Means within a column followed by the same letter do not differ significantly (0.1 level).

[b]Chisel = conventional chisel tillage system, reduced = reduced tillage system, row = no tillage except one sweep cultivation, strip = no tillage except row raking at planting, no-till = no tillage.

organic C), with the strip tillage system resulting in the lowest C mineralization and C turnover during the 30 d incubation compared to the chisel tillage system (Table 5). However, increased tillage intensity tended to increase N mineralization during the incubation, with the no-till system having a significant increase in N mineralization compared to the more intensively tilled systems (Table 5). The higher N mineralization with the no-till system indicated that the observed trends for a lower C mineralization and C turnover with the conservation tillage systems was not due to N limitations in these tillage system. Therefore, N immobilization alone was not the limiting factor to C mineralization and the higher organic C level observed in the conservation tillage systems was not due to a short-term reduction in N availability to microbial decomposers.

The ratio between C mineralization to N mineralization during the incubation, considered to be an index of the recalcitrant C levels in soil, indicated a decrease in the recalcitrant C level in soil (Nadelhoffer et al., 1991; Wood et al., 1994). At the 0-10 cm depth, the C:N mineralization ratio decreased as the level of tillage intensity decreased (Table 5). This indicated that the accumulation of organic C in the conservation tillage systems may be of more recalcitrant forms of C. Therefore, the more intensively tilled soil had a higher potential for C mineralization and a greater potential for reductions in soil organic C levels

TABLE 6. Effect of soil fertility on C mineralization, C turnover, N mineralization, and C:N mineralization ratio at 0-10, 10-20, and 20-30 cm depth.

Fertility[b]	C mineralization	C turnover	N mineralization	C:N mineralization
	(mg kg^{-1})			
0-10 cm				
High	347 a	1.68 a	6.89 a	63 a
Low	325 a	1.64 a	11.27 b	65 a
10-20 cm				
High	195 a	1.26 a	15.05 a	23 a
Low	197 a	1.28 a	11.47 a	63 a
20-30 cm				
High	155 a	1.14 a	15.93 a	14 a
Low	150 a	1.07 a	10.93 b	56 a

[a]Soil incubated at 25°C for 30 days. Values represent means of 5 replicates. Means within a column followed by the same letter do not differ significantly (0.1 level).

compared to less intensively tilled systems. This would be consistent with finding of Follett and Schimel (1989), which indicated that greater tillage intensity reduced microbial C availability.

Changes in the physical structure of soil due to tillage may be responsible for these observed changes in the potential soil C and N mineralization. Cambardella and Elliott (1993, 1994) reported that increased tillage intensity changed residue decomposition due to alteration in soil structure. They reported that macroaggregation, promoted by a reduction in tillage intensity, physically protected soil organic matter from microbial decomposition. They found that soil with a no-till production system had more C and labile N associated with macroaggregates compared to more intensely tilled soils. Also, Killham et al. (1993) using ^{14}C techniques to track organic matter decomposition, reported that soil pore size affects microbial decomposition of plant residue. Both the soil pore size distribution and the soil structure can be greatly altered with the tillage systems used (Potter and Chichester, 1993).

At the 0-10 cm depth, the soil fertility treatment did not impact the C mineralization or C turnover levels during the 30 day incubation, but N mineralization was significantly decreased in the high soil fertility treatment compared to the low soil fertility treatment (Table 6). This was most likely caused by a reduction in N demand by microorganisms in the low fertility treatment compared to the high fertility treatment due to the lower biomass inputs in that treatment.

At the 10-20 and 20-30 cm depth, no significant differences were observed between either soil fertility level or soil tillage system for the C mineralization, C turnover, or C:N mineralization ratio. Likewise, at the 10-20 cm depth, no significant differences between treatments were observed for N mineralization. However, a significant N mineralization effect was observed at the 20-30 cm depth for both the soil fertility and soil tillage treatments (Tables 5 and 6). At the 20-30 cm depth, biomass inputs would be substantially from roots of the previous crop. At this depth, N mineralization due to tillage was the inverse of the biomass input levels observed. The row tillage treatment produced the highest and the no-till produced the lowest N mineralization values (Tables 2 and 5). This was most likely caused by a reduction in N demand by microorganisms causing a release of N with the lower biomass inputs as the decomposition of the root biomass progressed. With the high soil fertility treatment, N mineralization was increased, indicating that the higher N fertilizer inputs compensated for the increased biomass inputs at this depth (Table 6).

The direct association of potential N mineralization and biomass inputs observed with the tillage treatments at the 20-30 cm depth was absent at the 10-20 cm depth (Tables 2 and 5). Since the 20-30 cm depth was not affected by the direct impacts of tillage, this is further evidence that alterations in the soil environment at the 0-10 cm depth due to tillage, such as changes in soil structure, were responsible for the observed differences in C an N cycling in this soil.

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